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PRELIMINARY PERFORMANCE OF A VERTICAL-ATTITUDE TAKEOFF AND LANDING, SUPERSONIC-CRUISE AIRCRAFT CONCEPT HAVING THRUST VECTORING INTEGRATED INTO THE FLIGHT CONTROL SYSTEM

A. W. Robins, F. L. Beissner, Jr., C. S. Domack, and E. E. Swanson

KENTRON INTERNATIONAL, INC.
Aerospace Technologies Division
Hampton, Virginia

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Space Administration

Langley Research Center
Hampton, Virginia 23665

SUMMARY

A performance study has been made of a vertical attitude takeoff and landing (VATOL), supersonic-cruise aircraft concept having thrust vectoring integrated into the flight control system. Preliminary results indicate that high levels of supersonic aerodynamic performance can be achieved. Further, with the assumption of an advanced (1985 technology readiness) low bypass-ratio turbofan engine and advanced structures, excellent mission performance capability is indicated.

INTRODUCTION

The continuing interest within the National Aeronautics and Space Administration in establishing the technology base for efficient supersonic-cruise fighter aircraft is an outgrowth of an earlier joint NASA/USAF study of the feasibility of such vehicles. Early results of this study were published in reference 1. Some subsequent disciplinary output may be found in references 2 through 10. Since these efforts, emphasis has shifted to high persistance, supersonic-cruise vehicles, with highly sophisticated stability and control systems involving thrust vectoring, such as in references 11 and 12, or with greatly improved takeoff and landing characteristics to meet the desire by the military for enhanced forward area basing (see ref. 13). References 14 and 15 report results of studies of two vertical-attitude takeoff and landing (VATOL) concepts.

The present study vehicle is a VATOL concept configured to provide for landing and takeoff in a vertical attitude utilizing landing gear located in the tips of the wing and vertical tail. Further, trim and control of the vehicle in the standard operating mode is through vectoring of engine gross thrust. The assumption is made that in the landing operation, a fully automated system having high-rate perceptors and controls is used with the pilot retaining only the abort or continue options. The basic engine used in the study aircraft is an advanced technology low bypass-ratio turbofan representing 1985 technology readiness.

The purpose of this paper is to present a preliminary assessment of the characteristics of such a concept. Those characteristics covered are aerodynamics, weight, balance, and performance.

SYMBOLS

a.c.	aerodynamic center
A_x	cross-section area
b	wing span
$\bar{c}$	mean aerodynamic chord
c.g.	center of gravity
C_D	drag coefficient $(\frac{\text{drag}}{qS})$
C_L	lift coefficient $(\frac{\text{lift}}{qS})$
C_M	pitching moment coefficient $(\frac{\text{pitching moment}}{qS\bar{c}})$
h	altitude
L/D	lift-drag ratio
M	Mach number
q	freestream dynamic pressure
S	wing reference area
W	aircraft weight
x,y,z	Cartesian coordinates
Δ	increment

Subscripts:

f	friction
i	lift induced
LE	leading-edge
LET	leading-edge thrust
max	maximum
min	minimum

0	at zero lift
R	roughness
TE	trailing edge
W	wave

Abbreviations

EW	empty weight
MFW	maximum fuel weight
ZFW	zero-fuel weight

CONFIGURATION

Vehicle Concept

The concept of a vertical-attitude takeoff and landing (VATOL) airplane capable of high levels of supersonic performance evolved from an earlier study (ref. 11) of a tailless, supersonic, conventional takeoff and landing airplane utilizing engine thrust vectoring as its primary flight control system. The unique constraints presented by the supersonic VATOL concept resulted in development of the configuration shown in figure 1. Such a configuration would present several formidable technical challenges, among which are: structural and aerodynamic definition of the vehicle; design and integration of an advanced propulsion system including two-axis thrust vectoring capability; and development of the thrust-dependent stability and control system, including a full-authority automatic takeoff and landing capability.

The development of the unusual wing planform geometry was the result of several conflicting demands, beginning with the requirement to provide for take-off and landing on the wing and vertical fin tips. The high outboard wing and fin thickness ratios necessary to accommodate the landing loads led to very high outboard leading-edge sweeps to minimize supersonic wave drag. The high sweep angles were also required in order to provide clearance between the engine exhaust nozzle and the ground plane to minimize surface erosion and attendant foreign object and exhaust plume ingestion problems. With the propulsion system and the blended fuselage well forward, the wing area was required to be concentrated forward as well, resulting in the unusual shapes of the leading and trailing edges. The pods located at the tips of the wings and vertical tail house a tripod-type landing gear. The landing gear system consists of inflatable rubber doughnut-shaped devices which fold into the pods upon retraction, and was selected to provide high footprint area for an all-terrain capability. No provisions were made for landing in the horizontal attitude; however, a small retractable skid could be placed in the nose for emergency use.

The engine selected for the study is unresized and is an advanced technology, low bypass-ratio, augmented turbofan representing 1985 technology readiness. The sea level static, maximum augmented thrust rating of 31955 lbf yields an engine thrust-weight ratio, exclusive of the two-axis vectoring nozzle system, of 11.5. The proposed conceptual thrust vectoring system consists of a two dimensional, convergent-divergent section with a horizontal deflector to provide longitudinal vectoring, and a pair of movable sidewalls downstream of the deflector to provide lateral vectoring. The inlet system is a two-dimensional, mixed compression, vertical internal ramp arrangement located beneath the fuselage.

The control system for operation throughout the range of power-on/power-off conditions is a complex one in which fly-by-wire and a sophisticated stability augmentation system will be required. To accomplish longitudinal trim and control, dependence is primarily upon vectoring of nozzle gross thrust. About the pitch axis, center of gravity control by means of fuel transfer is used to enhance trim, while active, high-rate trailing-edge surfaces provide artificial static stability, with the nozzle providing both trim and control moments. Except at very low flight speeds, rolling moments are provided by conventional wing trailing-edge surfaces with sufficient spoiler input to achieve favorable yaw/roll coupling. At very low flight speeds, differential reaction jets in the wing tip pods are provided to produce rolling moments. Moments about all those axes in the throttle-back or power-off mode are provided by trailing-edge surfaces only.

The combination of limited outward visibility and vehicle instability in the vertical-attitude mode would almost certainly result in an untenable workload for the pilot. Hence, an automatic system for takeoff and landing operations would be required, perhaps with the pilot retaining only the proceed/abort option. The technology required for this capability is currently available, but the definition of such a system is beyond the scope of the present study.

Configuration Description

The study airplane resulting from the above considerations has a wing span of 25 ft, overall length of 52 ft, and overall height of 15 ft, as seen in conventional (horizontal) orientation. The basic airplane gross weight with

full internal fuel is 23352 lb, resulting in a airplane thrust-weight ratio of 1.368. The configuration has a wing reference area of 537.3 sq. ft, yielding a wing loading of 43.46 lb/ft^2 at basic gross weight.

As can be seen in the general arrangement drawing (fig. 1), the configuration employs moderate wing-body blending, and places the pilot beneath a conventional bubble canopy on the forebody. The unique landing gear arrangement in the wing and vertical tail tip pods requires a substantial amount of wing anhedral to provide an adequately stable platform on the ground. The large amount of wing twist present is also apparent. The wing thickness-chord ratio varies inversely with the local chord, ranging from four percent at the indicated side of body to ten percent at the theoretical tip. The airfoil section varies as well, changing from an NACA 65A series section inboard, blending to a 64A section at mid-span, then to a 63A section, and finally to symmetrical NACA four-digit sections approaching the tip. The vertical tail airfoil sections vary in much the same fashion as those of the wing, ranging from three percent thick at the root to 10.6 percent thick at the theoretical tip.

Figure 2 presents the interior arrangement of the study configuration. The interior arrangement was prepared with the aid of an interactive computer graphics program in order to verify component clearances and calculate internal volumes. The longitudinal disposition of fuel in the airplane, which is fuel-volume limited, facilitates fuel transfer for pitch trim and static margin control. Volume is also provided in the fuselage for avionics, environmental control, and other required subsystems. The fuselage is very compact, in part due to the elimination of conventional landing gear and its associated storage requirements. There are no provisions for internal payload; however, the configuration is equipped with hard points for air-to-air and air-to-ground weapons carriage.

WEIGHT AND BALANCE

The weight and balance analysis of the study aircraft concept was performed using statistical estimation methods. These methods were derived from actual summary weight statement data from post-1960 United States Navy and Air Force fighter and attack aircraft and were used on the baseline aircraft. The developed formulas were then modified to incorporate weight savings provided by applying factors for advanced technologies in materials and manufacturing methods for the year 2000 aircraft.

The baseline aircraft structural weight was based on conventional aluminum skin-stringer construction. The design maneuvering limit load factor used in determining structural weight was 5 g's. Although no detailed structural analysis was performed, a 20-percent wing weight penalty was included to account for landing gear placement in the wing tips.

The baseline aircraft gross weight is estimated at 23352 pounds with a zero fuel weight of 13995 pounds. Maximum onboard fuel is 9357 pounds. A summary weight breakdown and a center-of-gravity envelope are shown in table I and figure 3, respectively.

An assessment was also made of the impact of year 2000 engine and structural material technology on structural weight. An optimum mix of advanced composites, advanced aluminum, and superplastic formed/diffusion bonded titanium was assumed to reduce structural weight by 30 percent, and engine thrust-weight ratio improved from 11.5 to 13.5. The impact of these results on range are reported in the performance section.

AERODYNAMICS

Zero-Lift Drag

The buildup of zero-lift drag for the clean configuration is shown as a function of Mach number in figure 4. The values shown are those corresponding to an altitude of 40,000 feet. Skin friction drag values were found by the T' method of Sommer and Short (reference 16). Form drag was found by the subsequent application of geometry-dependent factors of reference 17, and roughness drag was estimated from empirical data. Wave-drag evaluation was accomplished by a method based on reference 18. The numerical model in the format of reference 19 is provided in table II, with a plot shown in figure 5. Note that the numerical model origin or nose point is at -2.0 feet. A feature of the program for wave-drag evaluation is an ability to define a minimum wave-drag fuselage area distribution through a set of constraining fuselage stations in a given assemblage of aircraft components at a given Mach number. This feature was used to define the fuselage cross-section-area distribution at the design Mach number of 2.0. The resulting Mach 2.0, average-equivalent-body area buildup is shown in figure 6.

Zero-lift drags for the aircraft with AIM120A missiles were based on the assumption that the airframe was carefully tailored to accept them. Wing-mounted missiles were semi-submerged with one side of a set of fins and wings tangent to the wing surface. For the corner-mounted missiles on the aircraft body, fin and wing tangency and body indentation for partial submergence of the missile body were again assumed. Wave drags (including interference) were calculated by a method based on reference 18, and skin friction drag by the

method of reference 16. Base drag calculations were dependent on the assumption of a base pressure coefficient of .23 at subsonic speeds and $0.5/M^2$ at supersonic speeds. Drag increments for the MK 84 stores were estimated by the method of reference 17. The drag coefficient increments which resulted are summarized in table III.

Lift-Dependent Drag

Supersonic lift-dependent drag (C_{D_i} and $\Delta C_{D_{LET}}$), as well as angle of attack and static longitudinal stability characteristics, were evaluated by the modified linear theory method of references 20 through 23. The numerical model used is in the format of reference 19 and is shown as table IV, with a machine plot shown as figure 7. Note that the origin or nose point of this numerical model is at zero. Figure 8 shows lift-dependent drag near the begin-cruise point (M = 2.0 and h = 55000 feet). The final supersonic drag values (or attainable-thrust values) are seen to very closely approach those for full leading-edge thrust, primarily because this unique configuration provides greatest leading-edge bluntness where there is greatest upwash. The difference between this polar and the no leading-edge thrust polar is an increment, ΔCD_{LET}, which contains not only that leading edge thrust attainable, but that unattainable portion which manifests itself as vortex lift (see reference 24). Lift-dependent drags for Mach numbers 1.2 and 1.6 as well as those for Mach number 2.0 are shown in figure 9.

Subsonic lift-dependent drag values for the configuration were estimated to fall between the full-leading-edge-thrust and no-leading-edge-thrust polars as

calculated by VORLAX--the vortex lattice method of reference 25. Figure 10 shows this relationship for the conditions of M = 0.8 and h = 40,000 feet. Calculation of induced drag could have been done by more rigorous methods such as that of reference 26, in which optimum flap settings could have been determined and applied, but such an effort was beyond the scope of this study. The significant amount of leading-edge thrust estimated to exist on this configuration, despite its fixed leading edges, is attributed to the fact that the greatest leading-edge bluntness occurs where leading-edge upwash is greatest. Figure 11 shows lift-dependent drag as estimated for the remaining subsonic Mach numbers of 0.6, 0.9, and 0.95.

Maximum Lift-Drag Ratio

Maximum lift-drag ratio as a function of Mach number is shown in figure 12. The zero-lift drags used in the generation of these values correspond to an altitude of 40,000 feet, throughout. Maximum values vary from about 9.0 at M = .90 to almost 6.2 at the cruise Mach number of 2.0.

Stability and Trim

Pitching moment characteristics were calculated for the subsonic and supersonic speed ranges by the methods of references 26 and 20 through 23, respectively. For the critical supersonic cruise point, wing twist was designed to generate sufficient zero-lift pitching moment for the configuration to be essentially self trimming over the entire weight range from before cruise to end of cruise. This is shown in figure 13, which superimposes the calculated values

of aerodynamic-center location on the center-of-gravity envelope previously presented. The center-of-gravity schedule for supersonic cruise (M = 2.0), and the begin-cruise and end-of-cruise weights are indicated. Static instability (center of gravity located aft of the aerodynamic center) is indicated for the lower speeds. Thus active controls would be a requirement from lift off, through transition, and throughout most of the subsonic speed regime. The low stability levels coupled with the high thrust and the high levels of control power associated with thrust vectoring should provide outstanding agility, particularly in the transonic speed regime. However, at flight speeds below that for transition to and from landing and takeoff, use of the reaction-control jets located in the wing tip pods would be required.

MISSION PERFORMANCE

Mission performance for the study aircraft was evaluated for primary, alternate, and close support missions. The design condition was with full internal fuel. Additional mission performance was evaluated for the impact of projected year 2000 materials technology on structural weight of the concept. Performance with some weapon loadings was also evaluated.

Since the subject aircraft is strictly vertical takeoff and landing, all mission performance includes substantial allowances of fuel flow for one minute of engine operation at maximum thrust at takeoff and one minute at military rated thrust at landing. This allowance should prove suitable for an actual vertical lift off, conversion to conventional airborne flight and acceleration to a normal climb profile (computed starting at M = .3 at sea level) and the reverse maneuver of deceleration, reconversion and vertical landing (at a substantially reduced weight).

The primary mission ground rules and fuel allowances for this study consist of:

- Takeoff allowance - one minute at maximum thrust
- Climb and accelerate to cruise condition
- Cruise at M = 2.0 at best altitude
- Execute 540° maximum sustained turn at M = 2.0
- Release weapons
- Cruise back at M = 2.0 at best altitude
- Descend at best lift-drag ratio
- Landing allowance - one minute at military thrust
- Reserves - five percent of total fuel

Energy continuity is maintained throughout the mission.

The primary mission radius for the baseline aircraft was 671 n.mi. The performance summary is shown in table V. The comparable mission radius for the year 2000 structural technology aircraft was 744 n.mi. Since the aircraft is volume limited, this radius improvement is accomplished with the same amount of fuel and is due only to weight reduction. The addition of four AIM-120As (semi submerged) to these two aircraft results in mission radii of 591 and 658 n.mi., respectively. These results are included in table VI.

The alternate mission for this study includes:

- Takeoff allowance - one minute at maximum thrust
- Climb and accelerate to cruise condition
- Cruise to 250 n.mi. at M = 2.0 and best altitude
- Execute maximum sustained turn at maximum thrust at M = 1.6 as long as possible (this is the figure of merit for the alternate mission)
- Release weapons

- Cruise back at M = 2.0 at best altitude
- Descend at best lift-drag ratio
- Landing allowance - one minute at military thrust
- Reserves - five percent of total fuel

Energy continuity is maintained except as noted at mid-mission. The alternate mission performance for the baseline aircraft yields a maneuver time of 25.0 minutes at around 2 g's at M=1.6 and an altitude of 65000 ft when loaded with four AIM-120As. All alternate mission capability is included in table VI. Maximum sustained turn performance has been estimated with the 4 AMRAAM store loading and is presented in figure 14.

The close support mission was included to determine the effectiveness of this aircraft in a military support, self escort mission. The year 2000 technology aircraft was evaluated on the basis of up to 10% thrust increase being available (due to increased engine turbine inlet temperature and overspeed) for overload VTO. The payload consists of two 2000 lb MK-84 bombs which are released at the combat area plus two AIM-120A AMRAAM's which are retained for self defense against airborne threats. The mission rules are:

- Takeoff allowance - one minute at maximum thrust
- Climb and accelerate to cruise condition
- Cruise at best speed and best altitude to 250 n.mi.
- Military descent - no fuel, no distance
- Battlefield persistence - 2g turns continuous at 300 knots at 100 ft altitude as long as possible
- Release two 2000 lb MK-84 bombs
- Climb and accelerate to cruise home
- Cruise at best speed and altitude
- Descend to home base at best lift-drag ratio

- Landing allowance - one minute at military thrust
- Reserves - five percent of total fuel

Energy continuity was maintained except as noted at mid-mission. Persistence in the battlefield area was 39.1 minutes (time required for over 41 full 360° 2g turns at 300 knots at sea level). The mission performance summary is shown in table VII.

All performance is based on standard day conditions and was computed using the Flight Optimization System described in reference 27.

CONCLUDING REMARKS

A performance study has been made of a vertical-attitude takeoff and landing (VATOL), supersonic-cruise aircraft concept having thrust vectoring integrated into the flight control system. The baseline aircraft was designed around an advanced (1985 technology readiness) low-bypass-ratio turbofan engine. Preliminary results indicate that high levels of supersonic aerodynamic performance can be achieved. Mission performance, which was also evaluated with variations in airframe structures technology, engine thrust characteristics, and weaponry, is indicated to be excellent.

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TABLE I. - GROUP WEIGHT SUMMARY

ITEM	LBF	C.G.
WING	2062	303
VERTICAL TAIL	298	436
FUSELAGE	3158	198
LANDING GEAR	815	576
STRUCTURE TOTAL	(6333)	(292)
ENGINE	3526	324
AIR INDUCTION SYSTEM	410	216
MISC. PROPULSION SYSTEMS	212	272
FUEL SYSTEM	639	332
PROPULSION TOTAL	(4787)	(313)
SURFACE CONTROLS	736	254
INSTRUMENTS	167	214
HYDRAULICS	232	409
ELECTRICAL	283	205
AVIONICS	552	84
FURNISHINGS	245	176
AIR CONDITIONING	275	198
SYSTEMS & EQUIPMENT TOTAL	(2490)	(187)
WEIGHT EMPTY	(13610)	(280)
CREW	215	176
UNUSEABLE FUEL	82	332
ENGINE OIL	88	324
INTERNAL FUEL	9357	291
USEFUL LOAD TOTAL	(9742)	(290)
ZERO FUEL WEIGHT	(13995)	(279)
GROSS WEIGHT	(23352)	(284)

TABLE II.- NUMERICAL MODEL OF STS-7 FOR USE IN ZERO-LIFT DRAG ANALYSIS.

STS7CDW--STS-7 UNTWISTED WAVE-DRAG MODEL..EXTRA FIN AF'S

1 1 -1 1 1 0 0 7 20 1 19 20 4 10 -3 10

537.27	24.318	24.5								SCXCG
0.0	.50	.75	1.25	2.50	5.00	10.0	15.0	20.0	30.0	XAF 10
40.0	50.0	60.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	XAF 20
4.016	2.0	-.32	30.384							AFORG 3
9.700	4.0	-.86	25.900							AFORG 4
15.797	6.0	-1.51	22.003							AFORG 5
22.250	8.0	-2.25	18.150							AFORG 6
30.203	10.0	-3.28	13.797							AFORG 7
40.000	12.0	-4.63	8.400							AFORG 8
42.801	12.5	-5.10	6.824							AFORG 9
0.0	.019	.028	.044	.083	.150	.256	.326	.377	.430	ZORD 3-1
.408	.356	.288	.206	.163	.120	.073	.032	-.007	-.040	ZORD 3-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 4-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 4-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 5-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 5-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 6-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 6-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 7-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 7-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 8-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 8-2
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 9-1
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	ZORD 9-2
0.0	.304	.368	.469	.647	.875	1.213	1.459	1.645	1.892	WORD 3-1
1.997	1.954	1.743	1.402	1.195	.967	.729	.489	.250	0.0	WORD 3-2
0.0	.304	.368	.469	.647	.875	1.213	1.459	1.645	1.892	WORD 4-1
1.997	1.954	1.743	1.402	1.195	.967	.729	.490	.250	0.0	WORD 4-2
0.0	.346	.421	.533	.735	1.014	1.391	1.652	1.848	2.092	WORD 5-1
2.167	2.046	1.771	1.390	1.169	.938	.705	.501	.241	0.0	WORD 5-2
0.0	.412	.496	.628	.871	1.207	1.658	1.968	2.191	2.450	WORD 6-1
2.488	2.327	2.003	1.555	1.302	1.045	.786	.528	.270	0.0	WORD 6-2
0.0	.611	.742	.947	1.307	1.777	2.341	2.673	2.869	3.001	WORD 7-1
2.902	2.647	2.282	1.832	1.580	1.312	1.026	.724	.405	0.0	WORD 7-2
0.0	.916	1.114	1.420	1.961	2.666	3.512	4.009	4.303	4.501	WORD 8-1
4.352	3.971	3.423	2.748	2.370	1.967	1.539	1.086	.605	0.0	WORD 8-2
0.0	1.018	1.237	1.578	2.178	2.962	3.902	4.455	4.782	5.002	WORD 9-1
4.837	4.412	3.803	3.053	2.634	2.187	1.710	1.207	.672	0.0	WORD 9-2
-2.0	0.0	3.0	6.0	8.0	10.0	11.	12.	14.0	16.0	XFUS 1
18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	35.700	XFUS 2
0.0	.052	.164	.290	.403	.630	.868	1.152	1.320	1.300	ZFUS 1
1.213	1.068	.900	.726	.580	.464	.370	.292	.228	.180	ZFUS 2
0.0	1.20	4.60	8.40	9.70	11.12	11.93	12.47	13.26	13.47	AFUS 1
12.73	11.20	9.50	7.60	5.72	4.03	2.50	1.17	.32	0.0	AFUS 2
13.300	0.0	-1.90								PODORG 1
0.0	2.70	4.70	6.70	10.70	14.70	16.70	18.70	20.70	22.40	XPOD 1
1.447	1.493	1.527	1.557	1.611	1.655	1.668	1.671	1.671	1.671	PODR 1
22.000	2.00	0.0								PODORG 2
0.0	3.0	6.0	8.0	10.0	12.0	13.7	14.7	15.8	17.2	XPOD 2
0.0	.484	.692	.744	.775	.736	.653	.544	.376	0.0	PODR 2
43.0	0.0	9.0								PODORG 3
0.0	1.8	2.4	3.0	3.8	4.6	5.6	7.0	8.0	9.0	XPOD 3
0.0	.290	.389	.394	.420	.444	.498	.453	.314	0.0	PODR 3
40.0	12.0	-5.6								PODORG 4
0.0	.40	1.0	2.0	3.5	5.0	6.5	8.4	10.0	12.0	XPOD 4
0.0	.056	.132	.222	.334	.430	.500	.551	.430	0.0	PODR 4
18.644	0.0	2.0	20.356	26.450	0.0	4.5	14.98			FNORG 1
0.0	1.25	5.0	10.0	20.0	30.0	50.0	70.0	85.0	100.0	XFIN 1
0.0	.342	.656	.908	1.231	1.418	1.467	1.056	.550	0.0	FNORD1-1
0.0	.443	.845	1.159	1.536	1.738	1.702	1.160	.589	0.0	FNORD1-2
26.450	0.0	4.5	14.98	34.533	0.0	7.0	10.347			FNORG 2
0.0	1.25	5.0	10.0	20.0	30.0	50.0	70.0	85.0	100.0	XFIN 2
0.0	.443	.845	1.159	1.536	1.738	1.702	1.160	.589	0.0	FNORD2-1
0.0	.628	1.207	1.658	2.191	2.450	2.327	1.555	.786	0.0	FNORD2-2
34.533	0.0	7.0	10.347	44.0	0.0	9.0	4.72			FNORG 3
0.0	1.25	5.0	10.0	20.0	30.0	50.0	70.0	85.0	100.0	XFIN 3
0.0	.628	1.207	1.658	2.191	2.450	2.327	1.555	.786	0.0	FNORD3-1
0.0	1.673	3.140	4.136	5.068	5.302	4.676	3.236	1.813	0.0	FNORD3-2

TABLE III. - DRAG COEFFICIENT INCREMENTS DUE TO STORES AT VARIOUS MACH NUMBERS. h = 40,000 FEET.

Configuration	Mach Number				
	.4	.8	1.2	1.6	2.0
Aircraft + 2 Body-mounted AIM120A missiles	.00020	.00017	.00034	.00043	.00049
Aircraft + 4 Wing-mounted AIM120A missiles	.00025	.00023	.00065	.00049	.00037
Aircraft + 2 Wing-mounted Mark 84 stores	.00253	.00274	-	-	-
Aircraft + 2 AIM120A missiles and 2 Mark 84 stores	.00273	.00291	-	-	-

TABLE IV.- NUMERICAL MODEL OF STS-7 FOR USE IN ANALYSIS AT LIFT.

```
STS7NLZ--STS-7 UNCAMBERED WING WITH TWIST B FOR ANLZ
  1   1   0   0   0   0   0   9  20   0                         0       0       0
537.27  24.318  24.500                                                                 SCXCG
0.0     .50     .75     1.25    2.50    5.00    10.0    15.0    20.0    30.0    XAF    10
40.0    50.0    60.0    70.0    75.0    80.0    85.0    90.0    95.0    100.0   XAF    20
0.0     0.0     0.0     36.0                                                    AFORG   1
3.083   1.0     -.13    33.017                                                  AFORG   2
6.016   2.0     -.32    30.384                                                  AFORG   3
11.700  4.0     -1.568  25.900                                                  AFORG   4
17.797  6.0     -2.546  22.003                                                  AFORG   5
24.250  8.0     -3.471  18.150                                                  AFORG   6
32.203  10.0    -4.305  13.797                                                  AFORG   7
42.000  12.0    -5.304  8.4                                                     AFORG   8
44.801  12.5    -5.625  6.824                                                   AFORG   9
0.0     .006    .010    .016    .033    .066    .136    .209    .316    1.180   ZORD 1-1
1.420   1.274   1.040   .798    .718    .676    .653    .638    .644    .682    ZORD 1-2
0.0     .010    .015    .025    .050    .100    .196    .303    .402    1.030   ZORD 2-1
1.230   1.073   .797    .614    .568    .533    .503    .482    .486    .568    ZORD 2-2
0.0     .019    .028    .044    .083    .150    .256    .326    .377    .430    ZORD 3-1
.408    .356    .288    .206    .163    .120    .073    .032    -.007   -.040   ZORD 3-2
0.0     .004    .006    .010    .019    .038    .076    .115    .153    .229    ZORD 4-1
.306    .382    .459    .535    .573    .611    .650    .688    .726    .764    ZORD 4-2
0.0     .006    .009    .016    .031    .062    .125    .187    .250    .375    ZORD 5-1
.500    .625    .750    .875    .937    1.000   1.062   1.124   1.187   1.249   ZORD 5-2
0.0     .007    .010    .017    .034    .069    .137    .206    .274    .411    ZORD 6-1
.548    .686    .823    .960    1.028   1.097   1.165   1.234   1.303   1.371   ZORD 6-2
0.0     .006    .009    .016    .031    .062    .124    .186    .248    .372    ZORD 7-1
.496    .621    .745    .869    .931    .993    1.055   1.117   1.179   1.241   ZORD 7-2
0.0     .004    .006    .011    .021    .043    .086    .129    .172    .257    ZORD 8-1
.343    .429    .515    .600    .643    .686    .729    .772    .815    .858    ZORD 8-2
0.0     .004    .005    .009    .018    .036    .072    .108    .143    .215    ZORD 9-1
.287    .359    .430    .502    .538    .574    .610    .646    .681    .717    ZORD 9-2
0.0     .180    .265    .435    .830    1.500   2.565   3.515   4.360   6.680   WORD 1-1
7.250   6.770   6.252   5.822   5.430   4.930   4.420   3.950   3.515   3.130   WORD 1-2
0.0     .045    .068    .116    .222    .474    1.145   2.200   3.580   6.400   WORD 2-1
6.815   5.695   5.316   4.935   4.626   4.252   3.835   3.400   3.047   2.746   WORD 2-2
0.0     .304    .368    .469    .647    .875    1.213   1.459   1.645   1.892   WORD 3-1
1.997   1.954   1.743   1.402   1.195   .967    .729    .489    .250    0.0     WORD 3-2
0.0     .304    .368    .469    .647    .875    1.213   1.459   1.645   1.892   WORD 4-1
1.997   1.954   1.743   1.402   1.195   .967    .729    .490    .250    0.0     WORD 4-2
0.0     .346    .421    .533    .735    1.014   1.391   1.652   1.848   2.092   WORD 5-1
2.167   2.046   1.771   1.390   1.169   .938    .705    .501    .241    0.0     WORD 5-2
0.0     .412    .496    .628    .871    1.207   1.658   1.968   2.191   2.450   WORD 6-1
2.488   2.327   2.003   1.555   1.302   1.045   .786    .528    .270    0.0     WORD 6-2
0.0     .611    .742    .947    1.307   1.777   2.341   2.673   2.869   3.001   WORD 7-1
2.902   2.647   2.282   1.832   1.580   1.312   1.026   .724    .405    0.0     WORD 7-2
0.0     .916    1.114   1.420   1.961   2.666   3.512   4.009   4.303   4.501   WORD 8-1
4.352   3.971   3.423   2.748   2.370   1.967   1.539   1.086   .605    0.0     WORD 8-2
0.0     1.018   1.237   1.578   2.178   2.962   3.902   4.455   4.782   5.002   WORD 9-1
4.837   4.412   3.803   3.053   2.634   2.187   1.710   1.207   .672    0.0     WORD 9-2
```

TABLE V. - DESIGN MISSION PERFORMANCE SUMMARY

Baseline Aircraft, Primary Mission, No Stores

	INITIAL	FUEL (LBF)		TIME (MIN)		DISTANCE (N.MI)		MACH NUMBER		ALTITUDE (FT)	
SEGMENT	WEIGHT(LBF)	SEGMENT	TOTAL	SEGMENT	TOTAL	SEGMENT	TOTAL	START	END	START	END
Start Engine	23352										
Takeoff	23352	865	865					0.0	0.3	0	0
Climb	22847	1226	2091	3.7	3.7	45.4	45.4	.3	2.0	0	64235
Cruise	21261	2813	4904	32.7	36.4	625.6	671.0	2.0	2.0	64235	65000
Turn*	18448	1120	6024	5.1				2.0	2.0	65000	65000
Cruise	17328	2148	8172	27.3	27.3	522.4	522.4	2.0	0.3	65000	65000
Descent	15180	315	8487	19.1	46.4	148.6	671.0	2.0	0.3	65000	0
Landing	14865	402	8889								
Reserves	14463	468	9357								
Zero Fuel	13995										

* Combat allowance consists of a 540 deg turn, maximum sustained g's, max power, at cruise altitude. (2.01 g's here)

TABLE VI. - PERFORMANCE COMPARISON

	TAKEOFF WEIGHT		PRIMARY MISSION	ALTERNATE MISSION	
	THRUST LOADING	WING LOADING	RADIUS (N.MI)	COMBAT TIME (MIN)	NUMBER OF 360° TURNS
Baseline Aircraft (No Stores)	1.37	43.5	671	28.9	8.7
Baseline Aircraft (4 AIM-120A)	1.27	46.7	591	25.0	7.7
Year 2000 Structural Weight Aircraft (No Stores)	1.54	38.5	744	31.0	10.3
Year 2000 Structural Weight Aircraft (4 AIM-120A)	1.42	41.8	658	26.8	9.1
Overload Close Support Aircraft*	1.34	48.8	-	-	-

* Year 2000 structural weight aircraft with 2-2000 lb MK-84 bombs plus 2 AIM-120A's.
VTO thrust provided by 1.1 Thrust Factor due to engine overspeed and overtemperature.

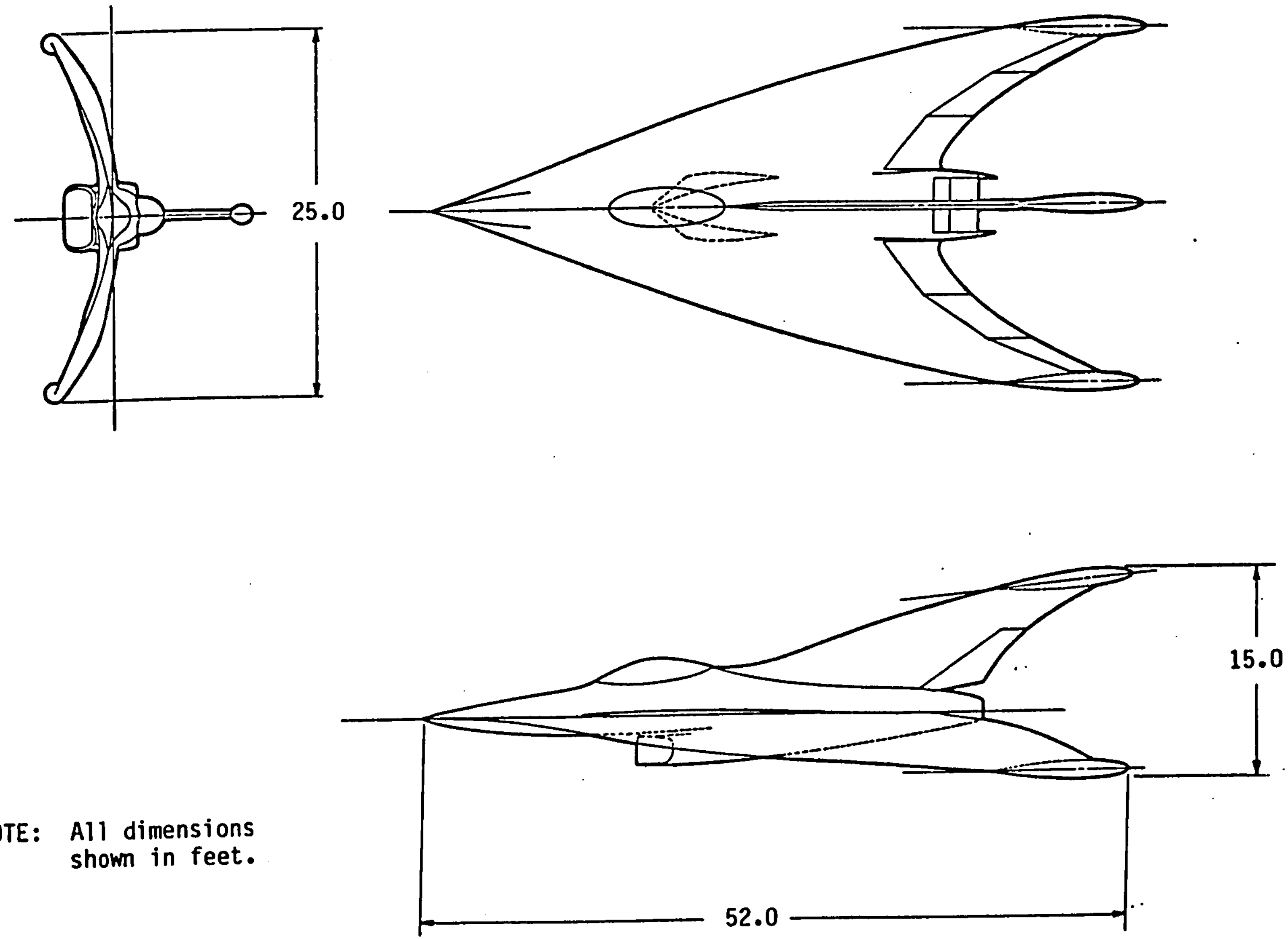
TABLE VII. - MISSION PERFORMANCE SUMMARY

Year 2000 Structural Weight Aircraft, *Overload Close Support Mission,
2-2000 lb MK-84 Bombs plus 2 AIM-120A's

	INITIAL	FUEL (LBF)		TIME (MIN)		DISTANCE (N.MI)		MACH NUMBER		ALTITUDE (FT)	
SEGMENT	WEIGHT(LBF)	SEGMENT	TOTAL	SEGMENT	TOTAL	SEGMENT	TOTAL	START	END	START	END
Start Engine	26200										
Takeoff	26200	865	865					0.0	0.3	0	0
Climb	25335	541	1406	1.6	1.6	11.2	11.2	.3	.85	0	31493
Cruise	24794	1514	2920	28.9	30.5	238.8	250.0	.85	.85	31493	32811
Turn**	23280	4427	7347	39.1				.454	.454	100	100
Release MK-84's	18853										
Climb	14913	406	7753	2.1	2.1	14.8	14.8	.454	.93	100	50136
Cruise	14507	453	8206	16.4	18.5	145.7	160.5	.93	.93	50136	50575
Descent	14054	281	8487	14.8	33.3	89.5	250.0	.93	0.3	50575	0
Landing	13773	402	8889								
Reserves	13371	468	9357								
Zero Fuel	12903										

* VTO Thrust provided by 1.1 Thrust Factor due to engine overspeed and overtemperature.

** Battlefield persistence consists of 2g turns at 300 KTAS, 100 ft altitude, stores on. (over 41 full 360° turns here)



NOTE: All dimensions shown in feet.

Figure 1. - General arrangement of the study vehicle.

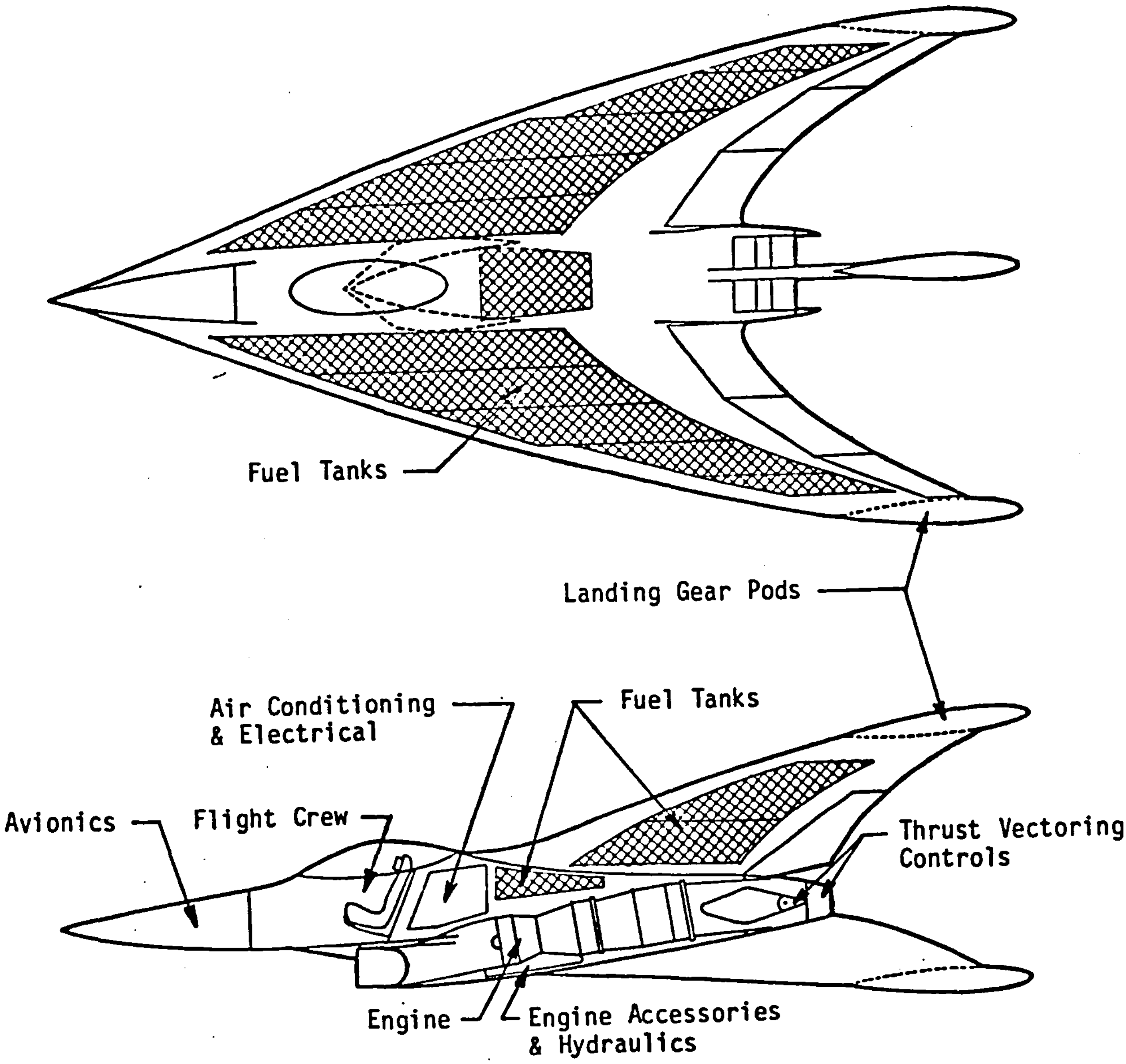


Figure 2. - Inboard profile.

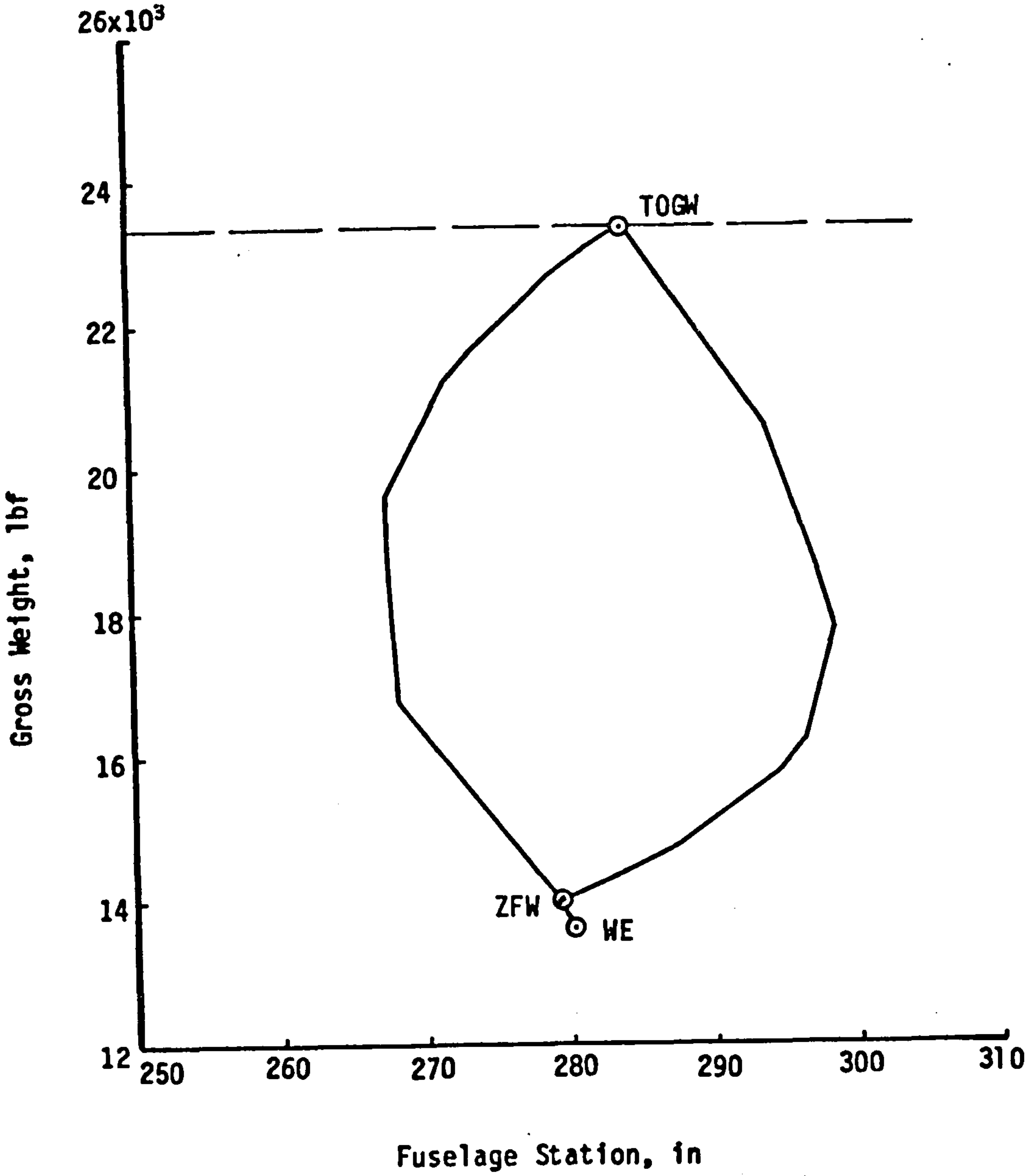


Figure 3. - Center-of-gravity envelope.

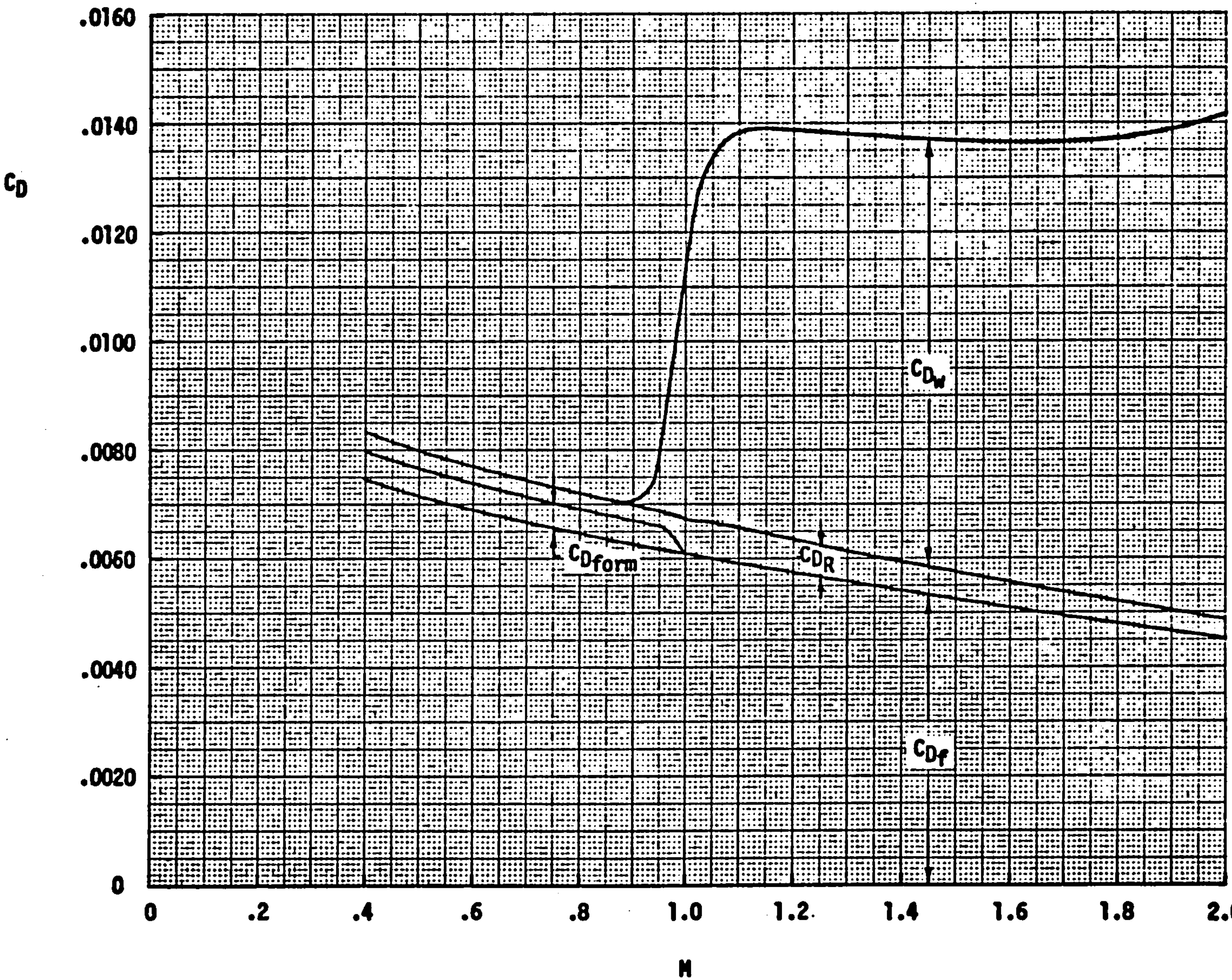


Figure 4. - Buildup of zero-lift drag coefficient as a function of Mach number. h = 40,000 feet.

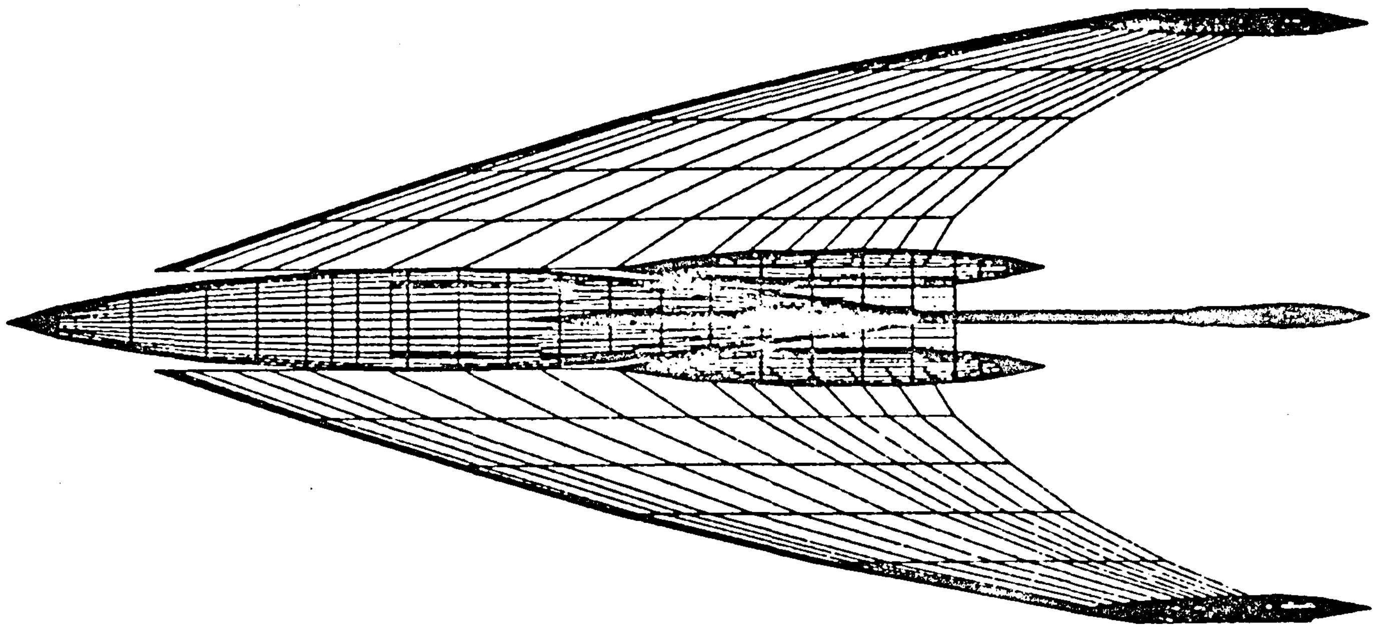


Figure 5.- Computer drawing of numerical model for wave drag analysis.

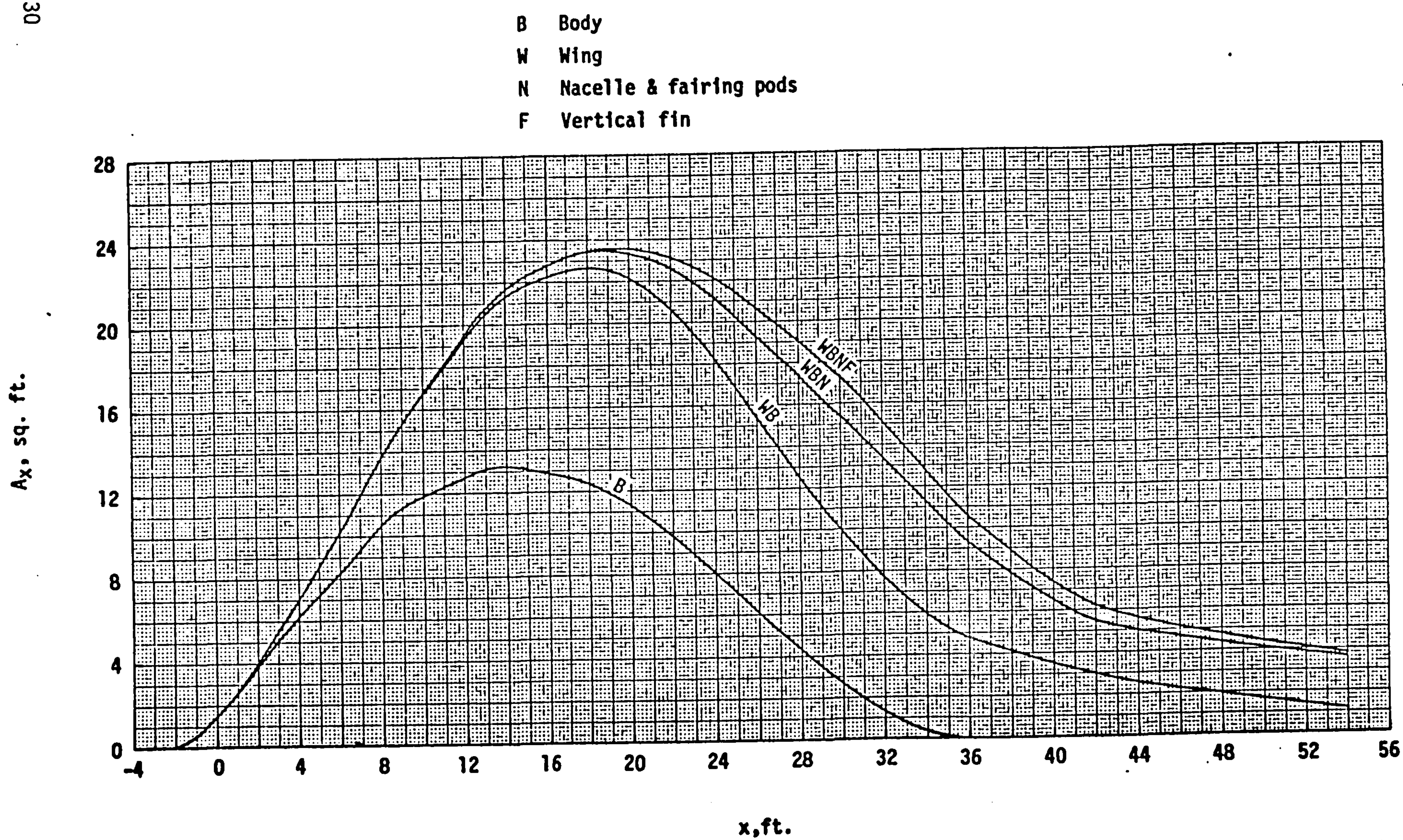


Figure 6. - Average equivalent-body area distribution at Mach 2.0 condition.

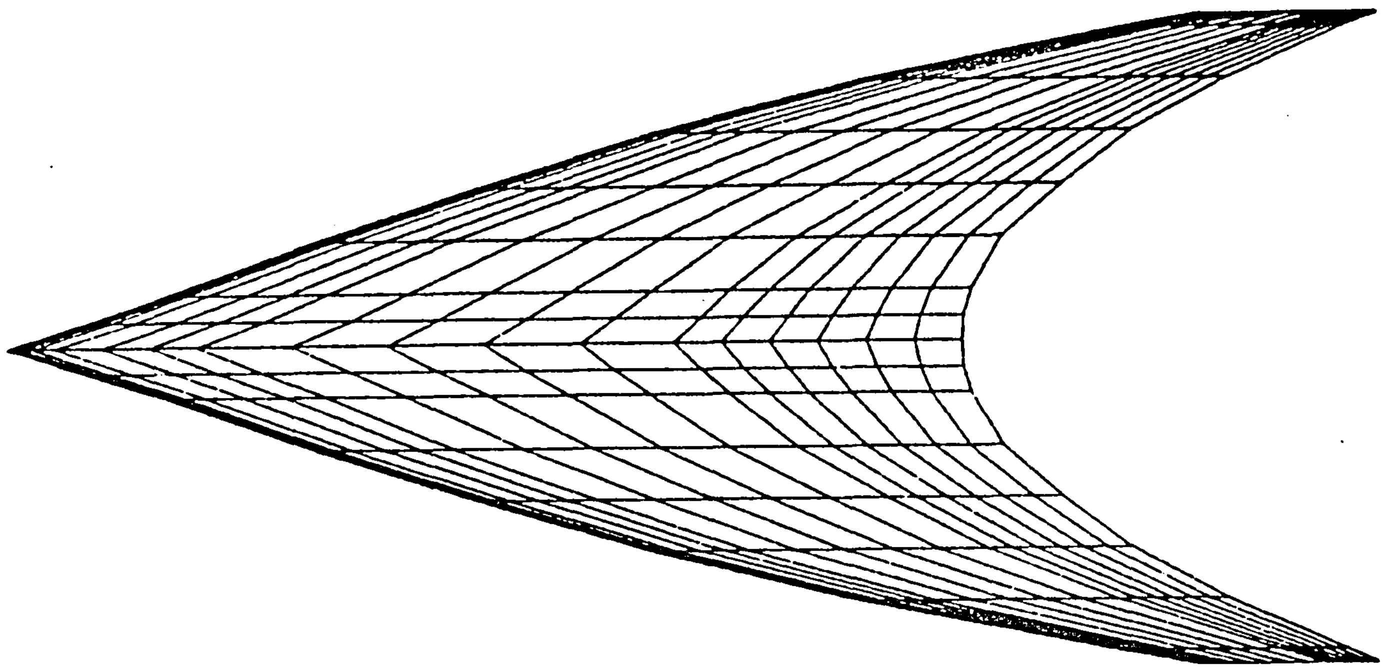


Figure 7.- Computer drawing of numerical model for analysis at lift.

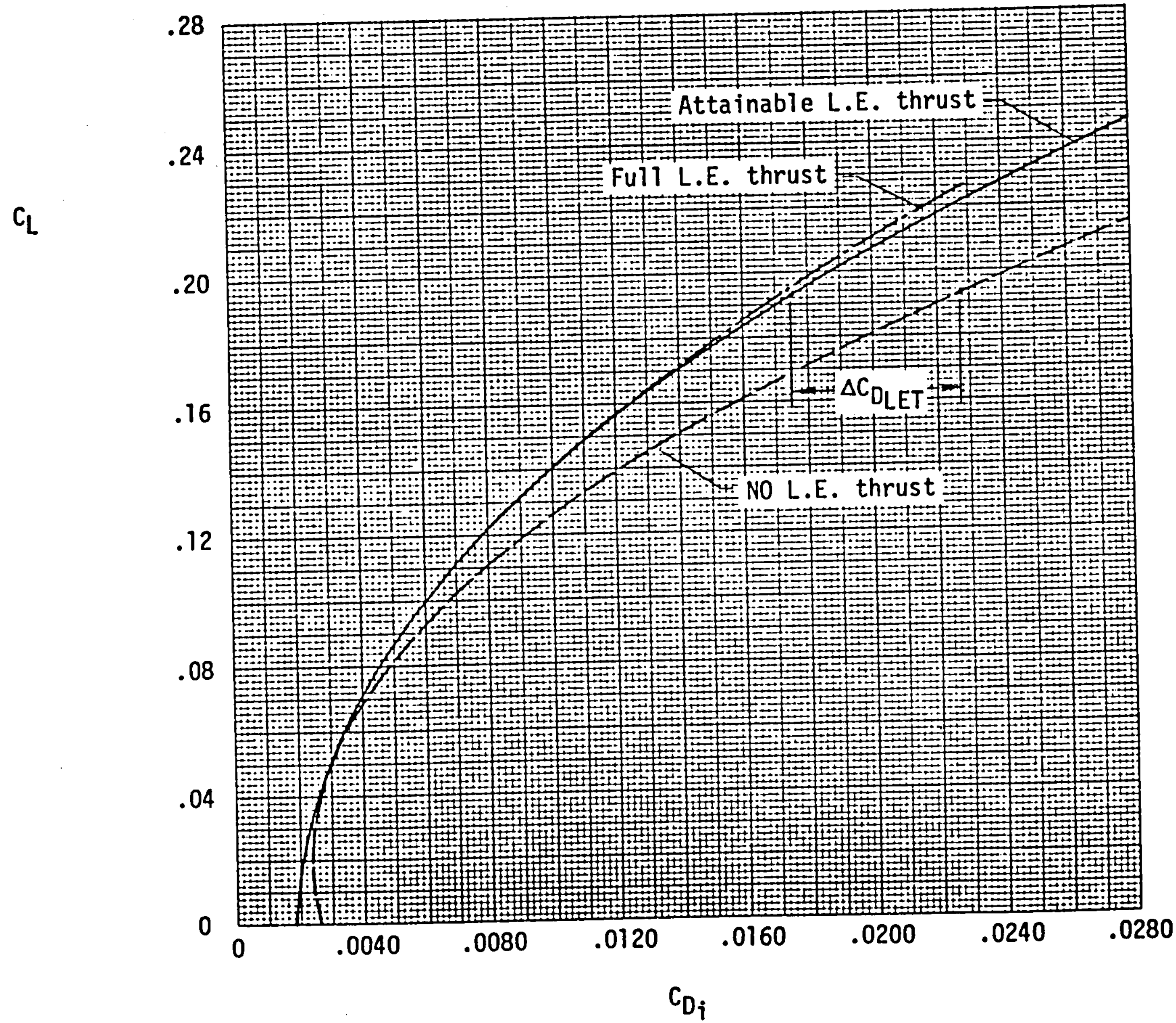


Figure 8.- Lift-dependent supersonic drag relative to the full- and no-leading-thrust polars at M = 2.0.

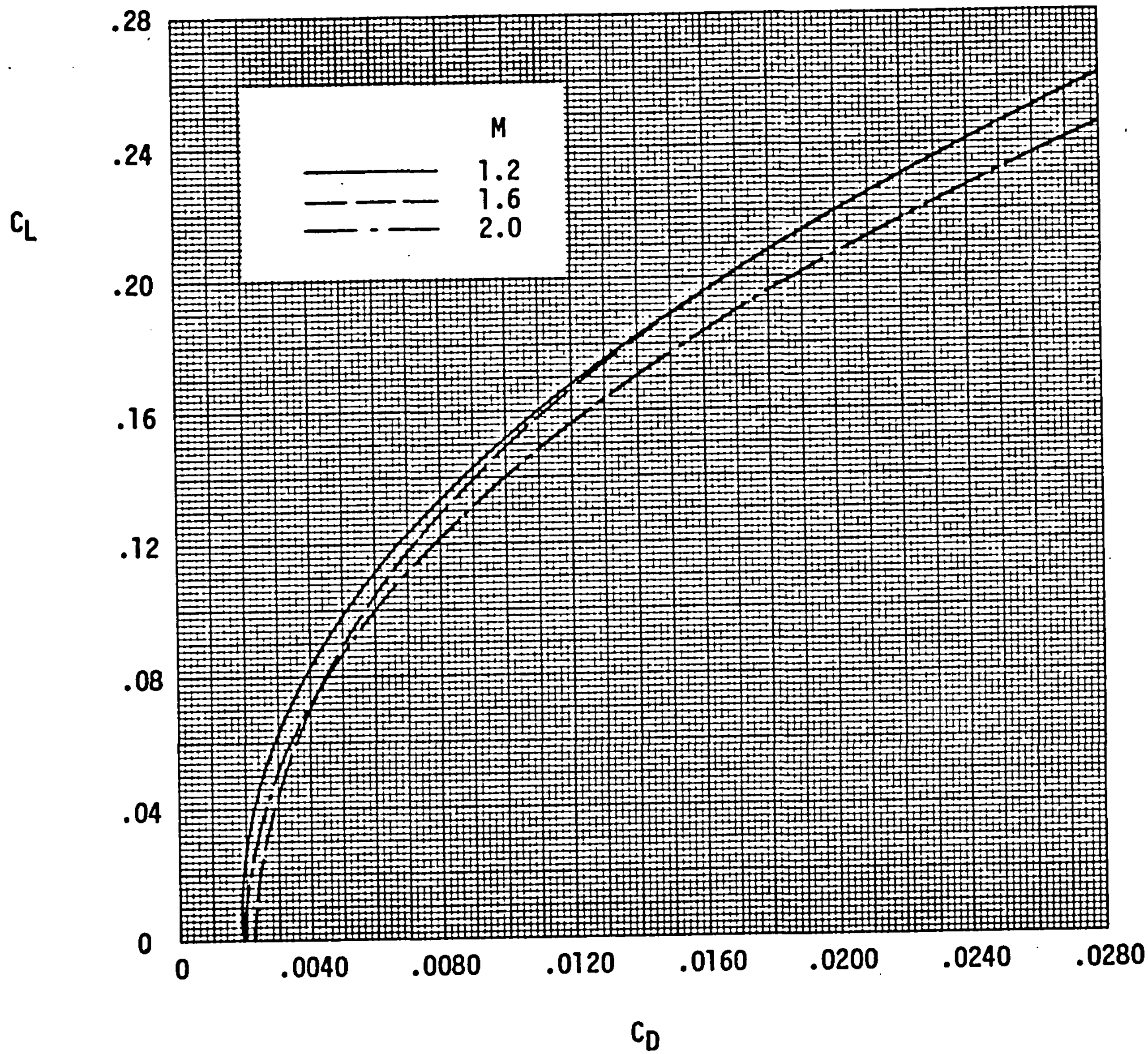


Figure 9.- Lift-dependent drag coefficients at supersonic speeds. Zero-lift drag values are for h = 40,000 feet.

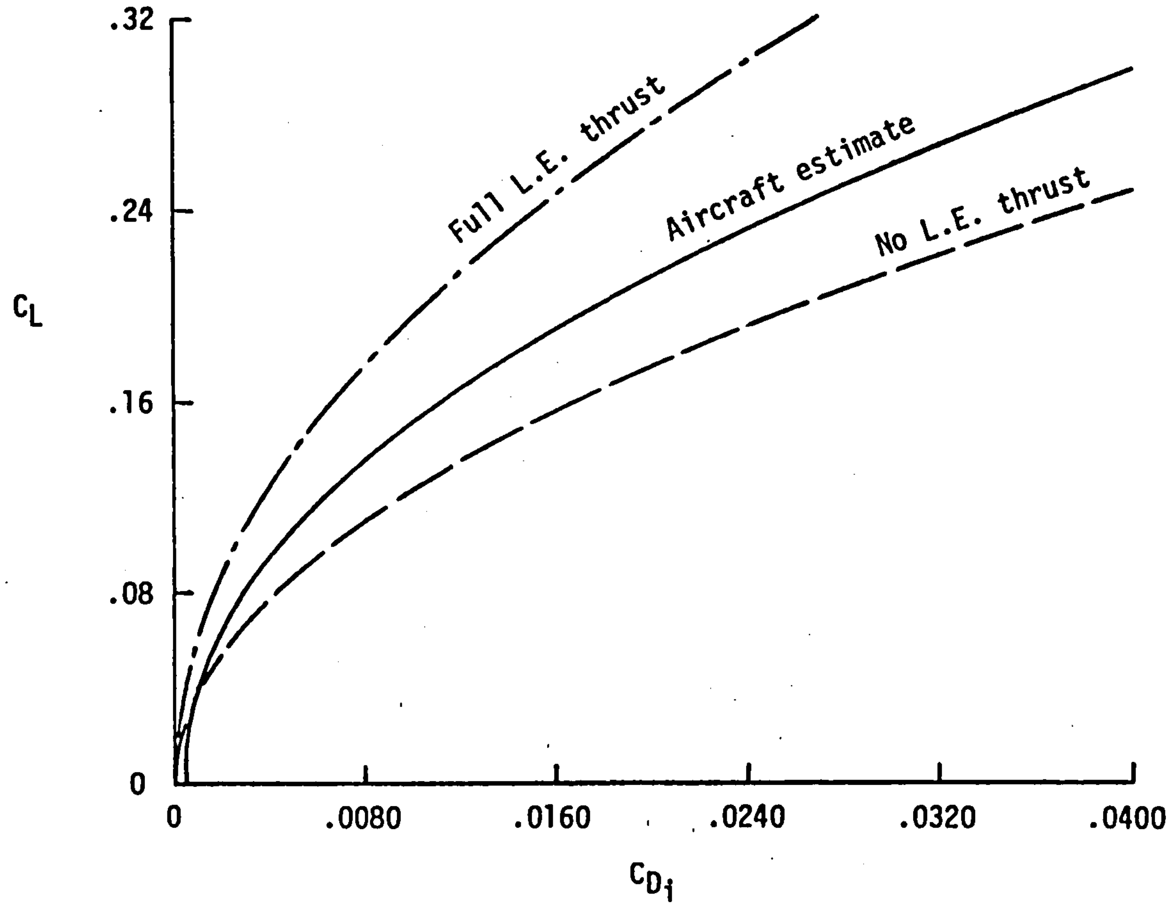


Figure 10.- Comparison of estimated drag polar with the full-thrust and no-leading-edge-thrust polars as calculated by VORLAX. M = 0.8 and h = 40,000 feet.

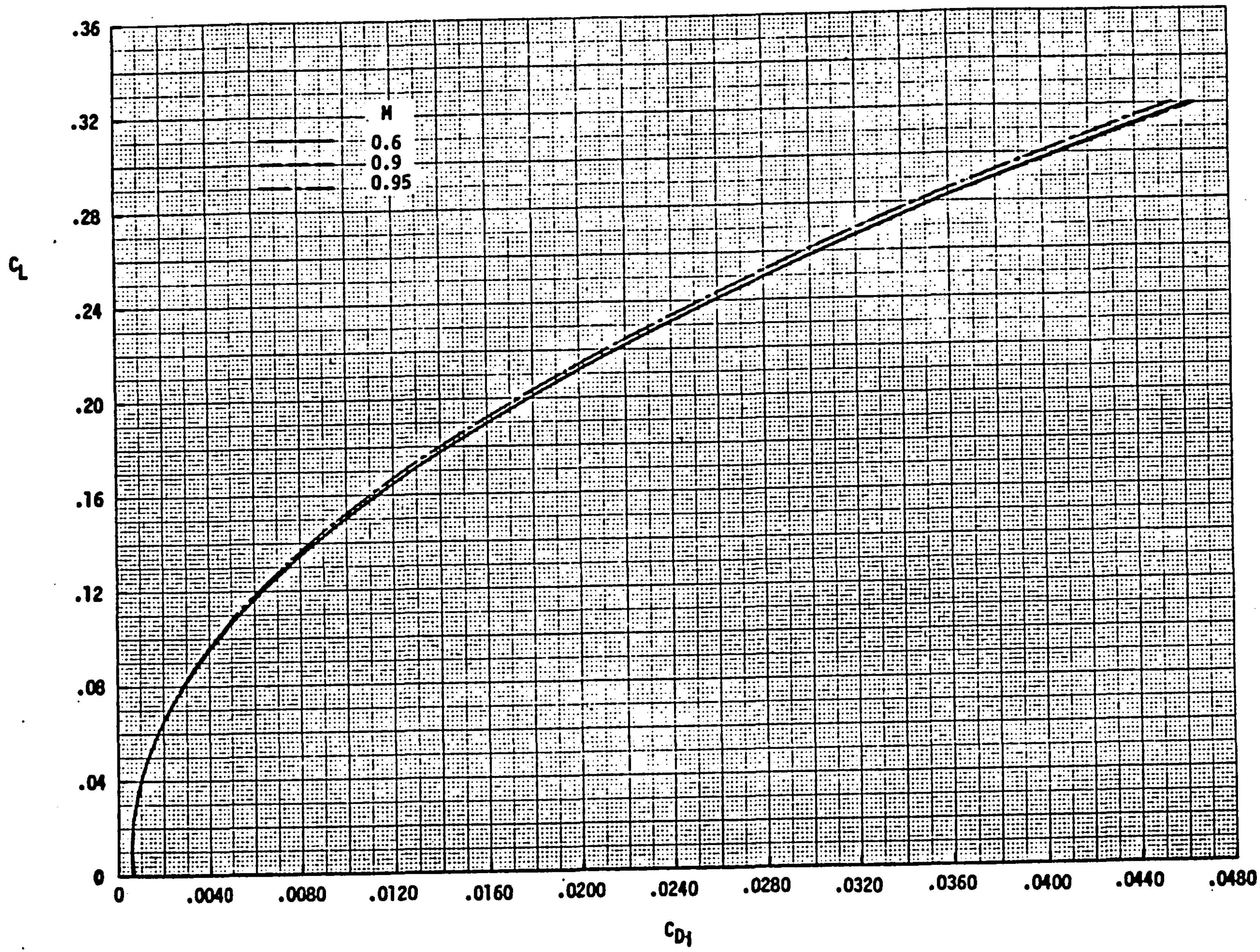


Figure 11. - Estimated lift-dependent drag coefficients at subsonic speeds . h = 40,000 feet.

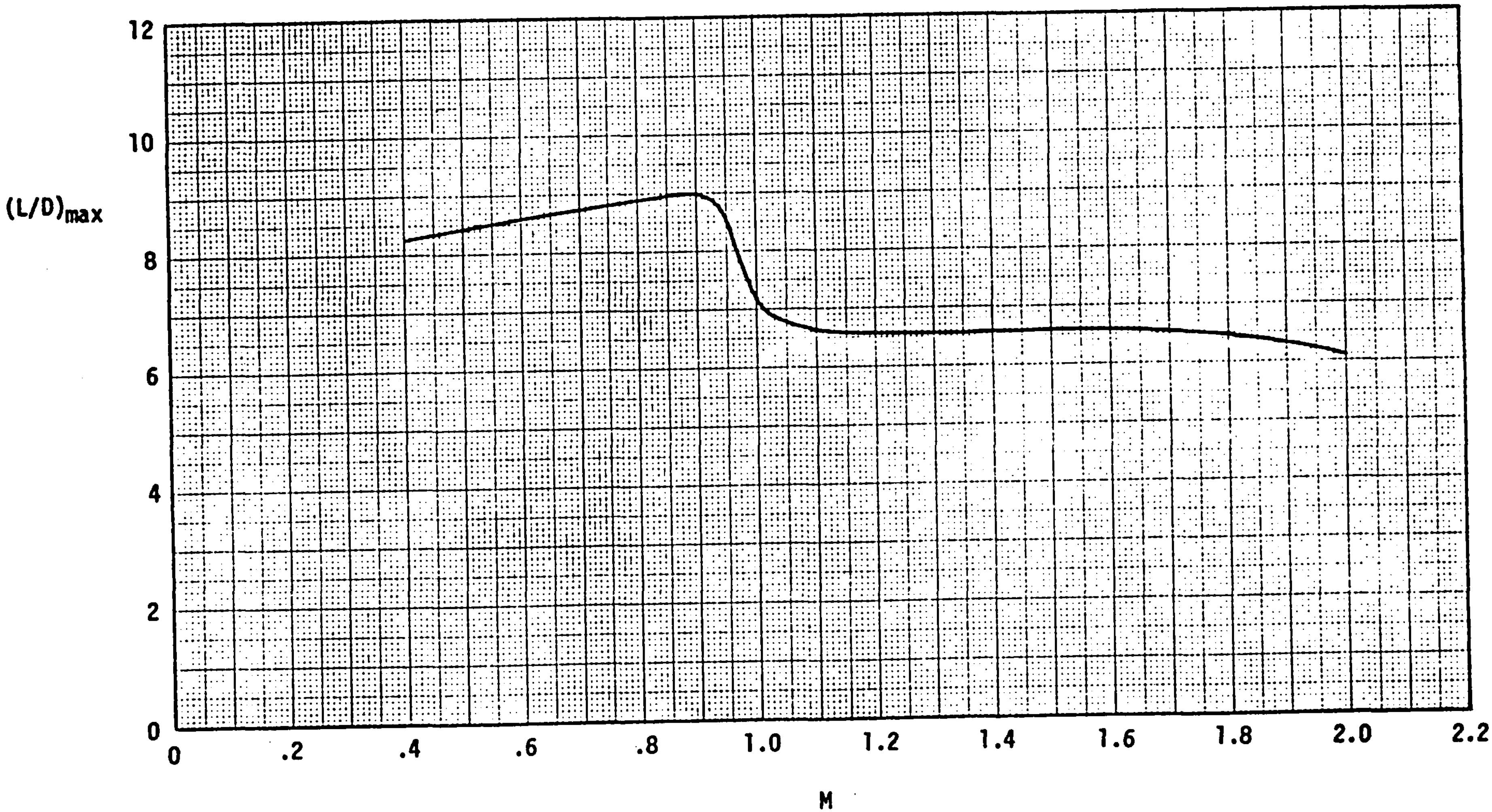


Figure 12.- Maximum lift-drag ratio versus Mach number. C_{D_0} values are for h = 40,000 feet.

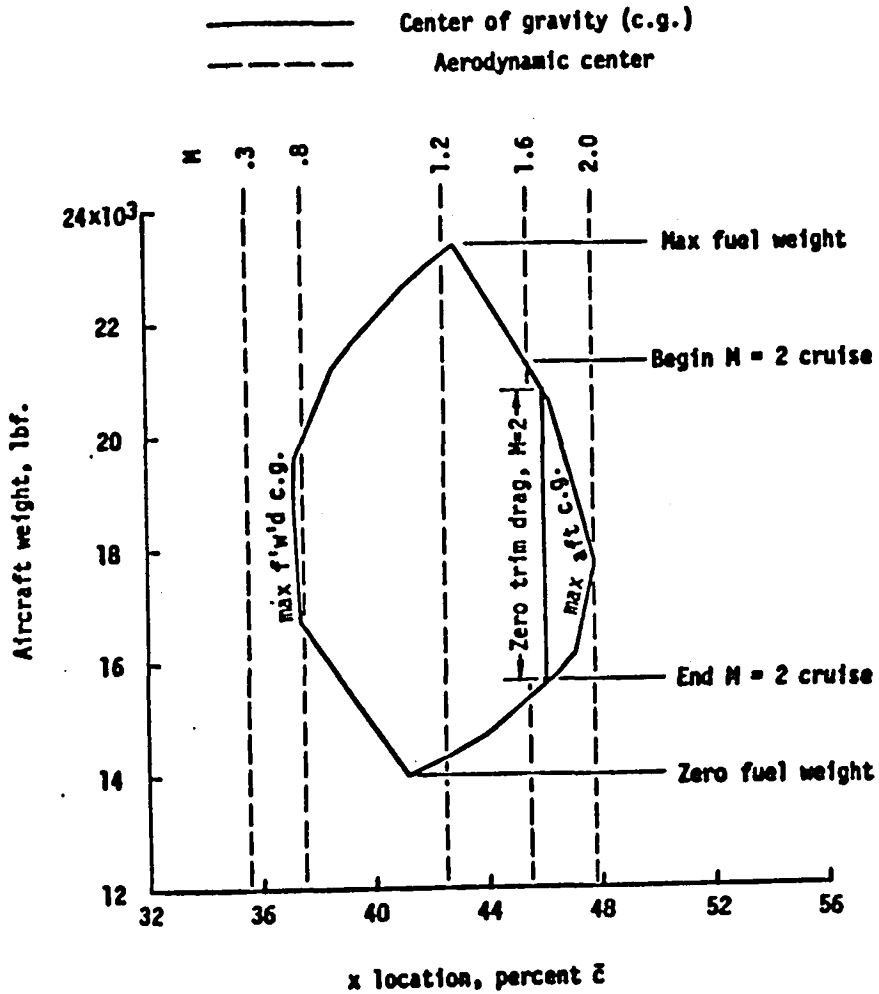


Figure 13. - Location from 0.3 = M = 2.0 of aerodynamic center with respect to center-of-gravity envelope.

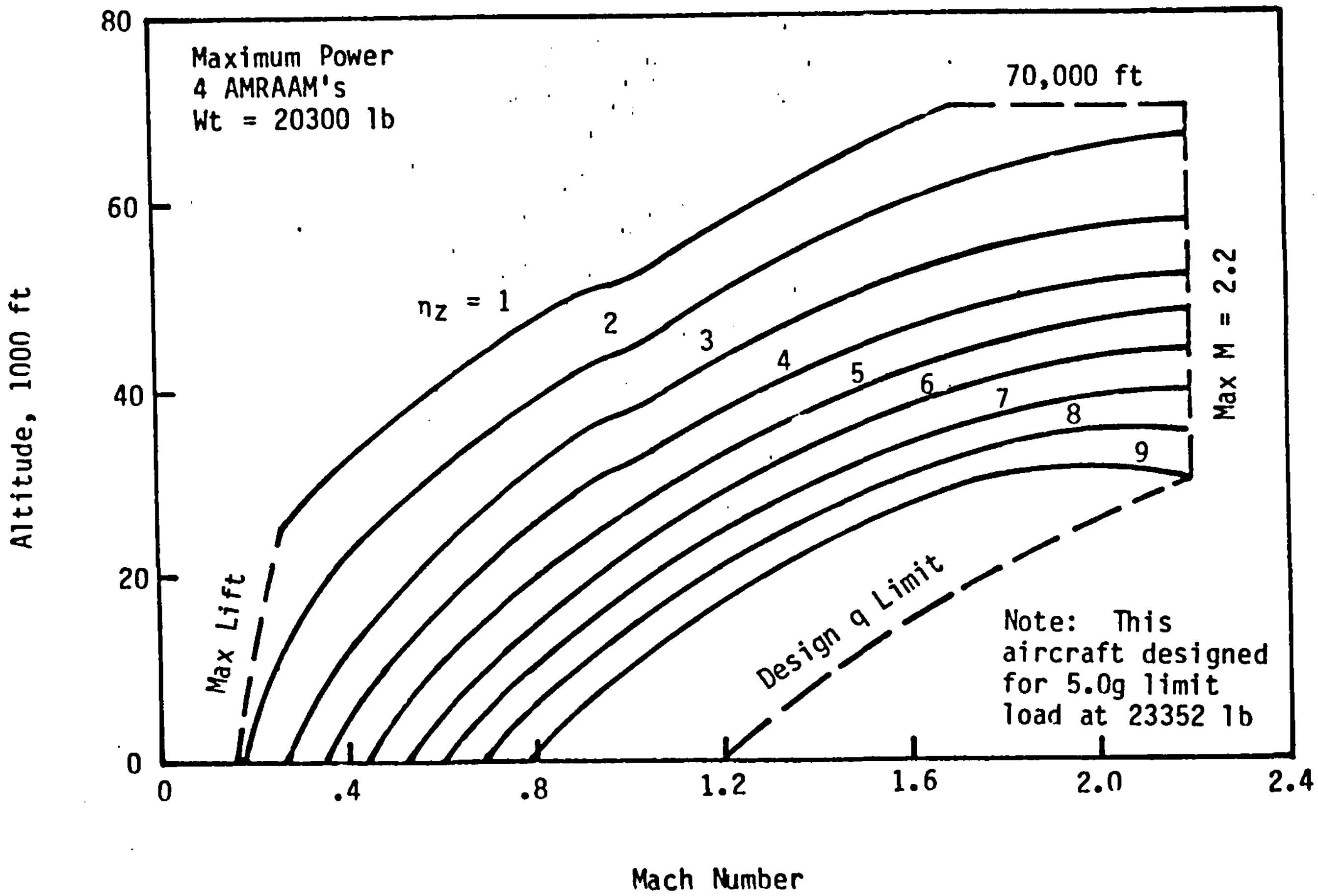


Figure 14. Maximum Sustained Turn Performance

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15. Supplementary Notes

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16. Abstract

A performance study has been made of a vertical attitude takeoff and landing (VATOL), supersonic-cruise aircraft concept having thrust vectoring integrated into the flight control system. Preliminary results indicate that high levels of supersonic aerodynamic performance can be achieved. Further, with the assumption of an advanced (1985 technology readiness) low bypass-ratio turbofan engine and advanced structures, excellent mission performance capability is indicated.

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